Mechanical Performance of Large Format Underwater Photomultiplier

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6/16/2012

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BROOKHAVEN
NATIONAL LABORATORY

Introduction

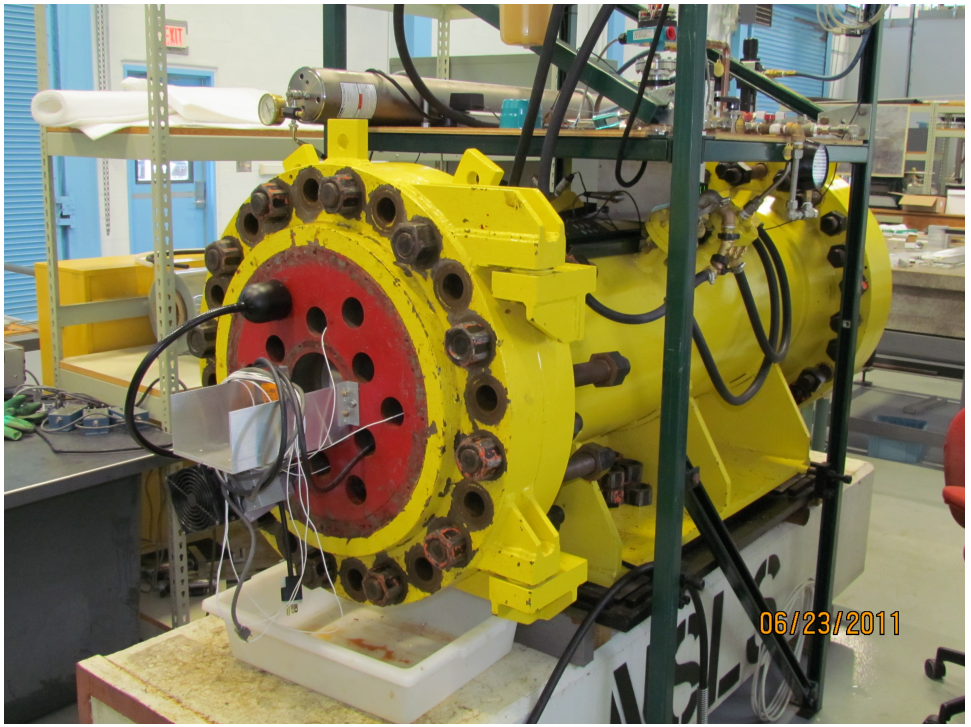
Large water Cerenkov detectors are important technology for neutrino physics from MeV to TeV energy range.

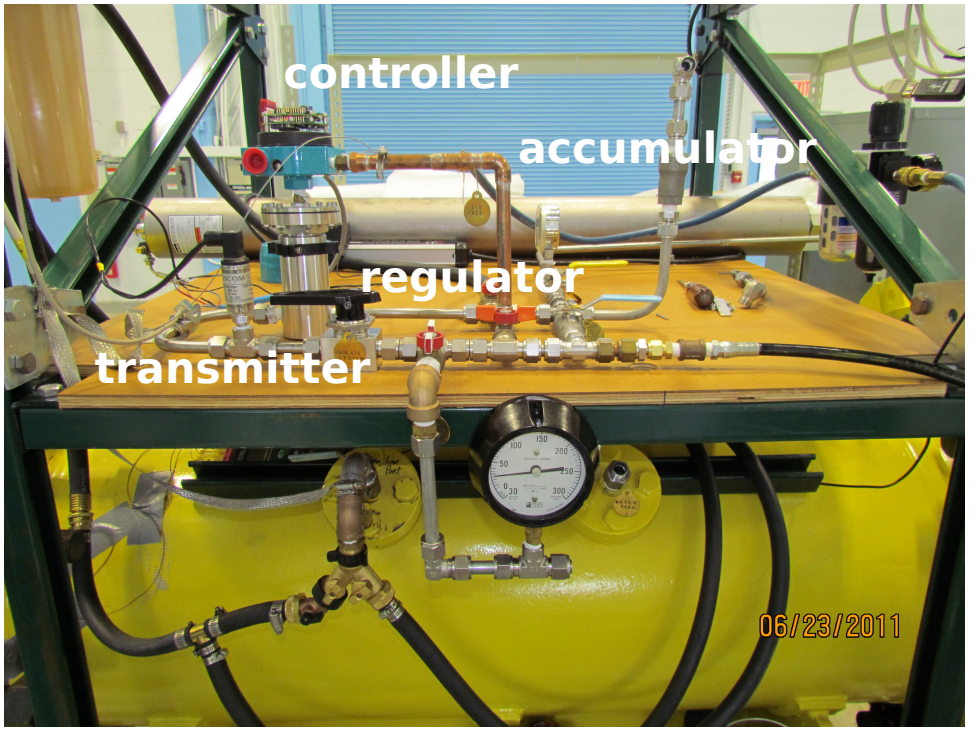
- Mechanic performance of large format semi-hemispherical photomultiplier (PMT) within large water Cerenkov detector
  - Determine if the PMT can withstand expected hydrostatic pressure and potential shock waves in the water
    - 6600 PMTs imploded in Super Kamiokande in a chain reaction by the shock wave in 2001
  - BNL hydrostatic pressure test
  - PMT underwater implosion test
    - Single PMT implosion test
    - Multiple PMTs cascade implosion test
  - PMT Implosion Simulation

Slow Rise Pressure Test

- Goal: Check the performance of glass under slow rise pressure conditions. How much strength of glass decreases (changes) if we rise the pressure slowly. This will help us to decide the correct pressure rating of PMT glass.
- Hydrostatic pressure tests:
  - Multiple different types of PMTs (10”, 11” and 12”) in 5 minutes / 2 hours / 24 hours cycle each (0-300psi)

BNL Slow Rise system

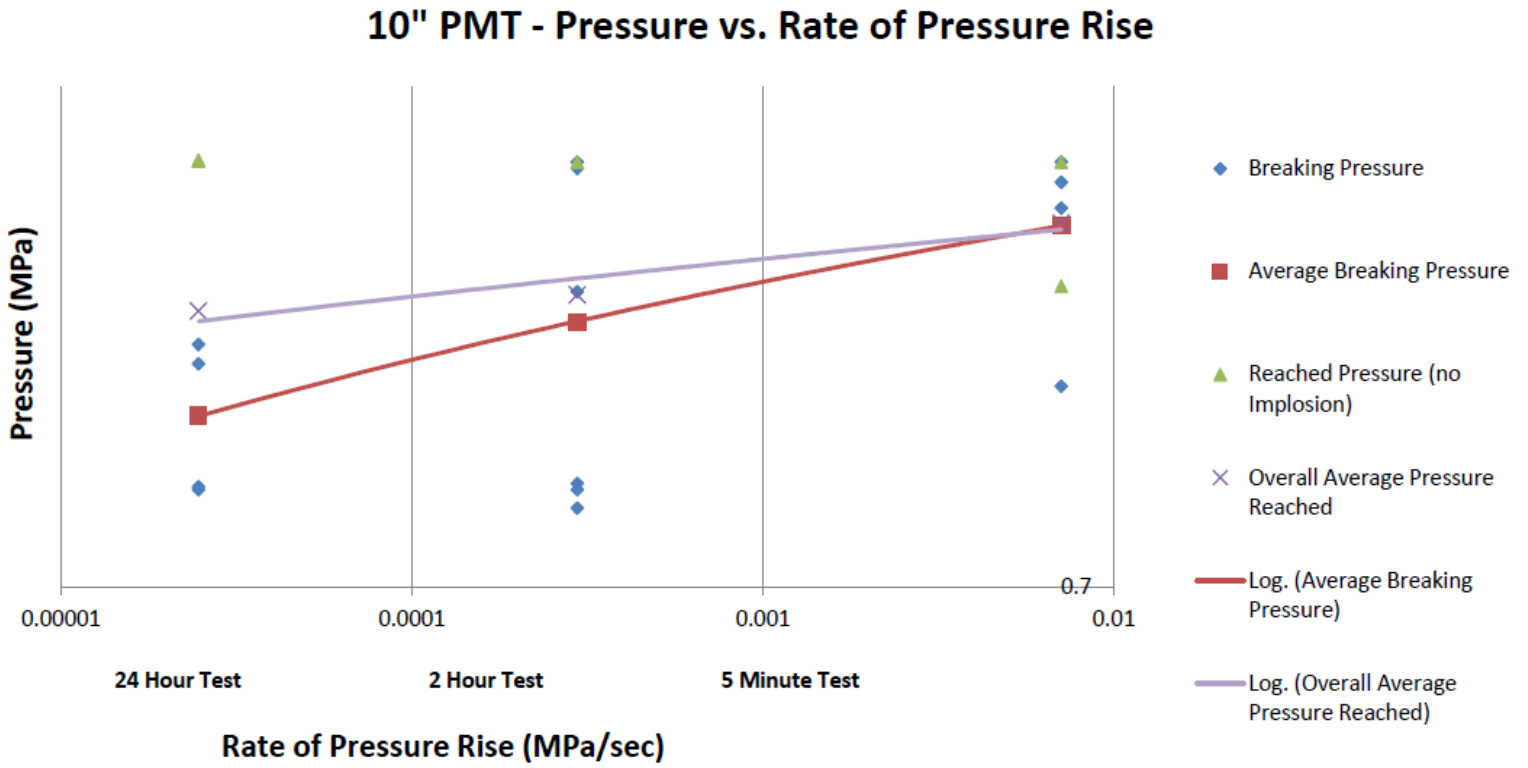




Slow rise system:

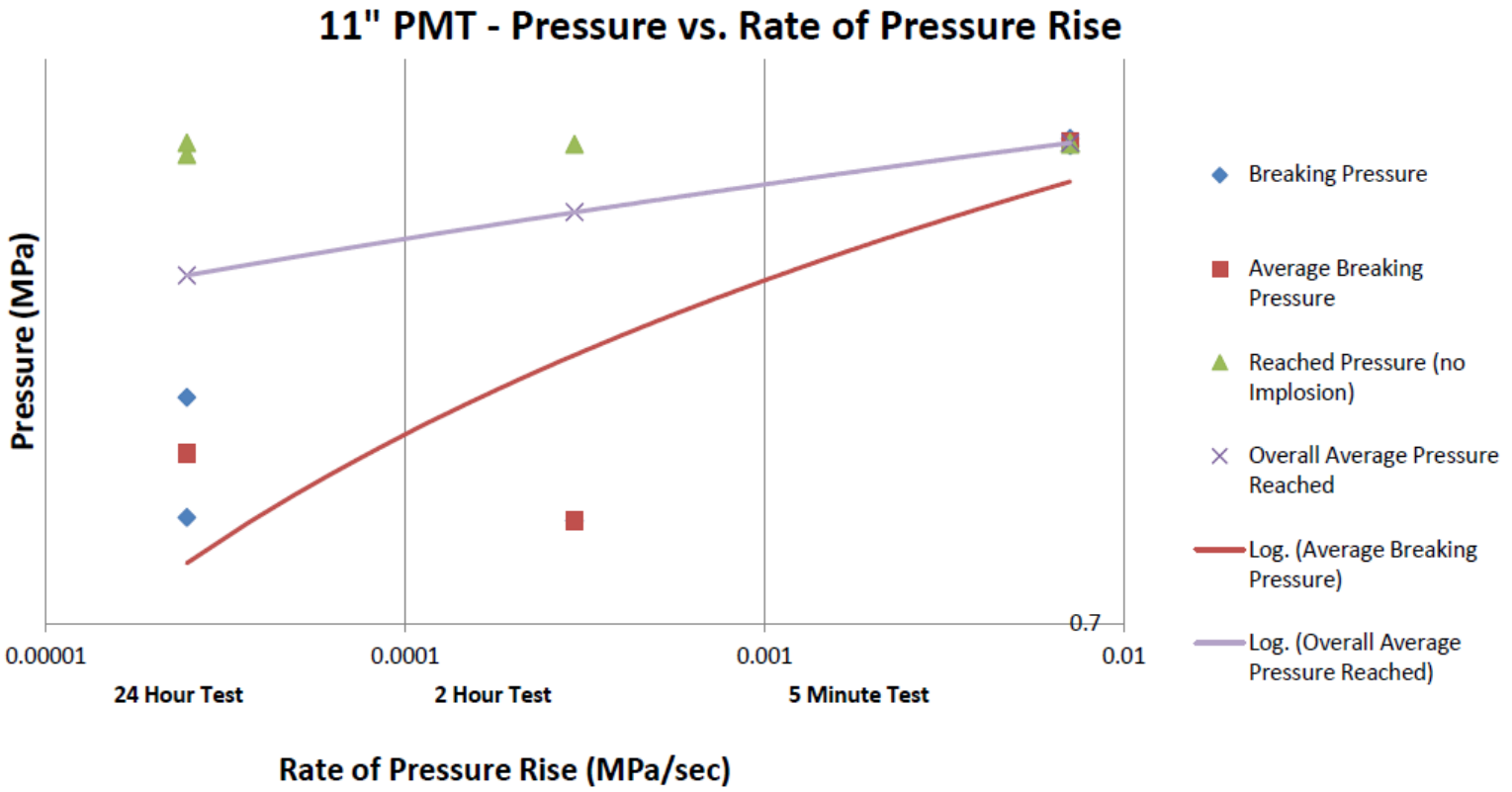
- BNL pressure vessel tank (50gal, up to 350psi)
- High pressure accumulator feed in (3gal, up to 2000 psi)
- Tap water feed in (up to 60 psi)
- Regulator / transmitter feed back
- ER3000 Electronic Pressure Controller
- Labview control the pressure rising function

10” PMTs



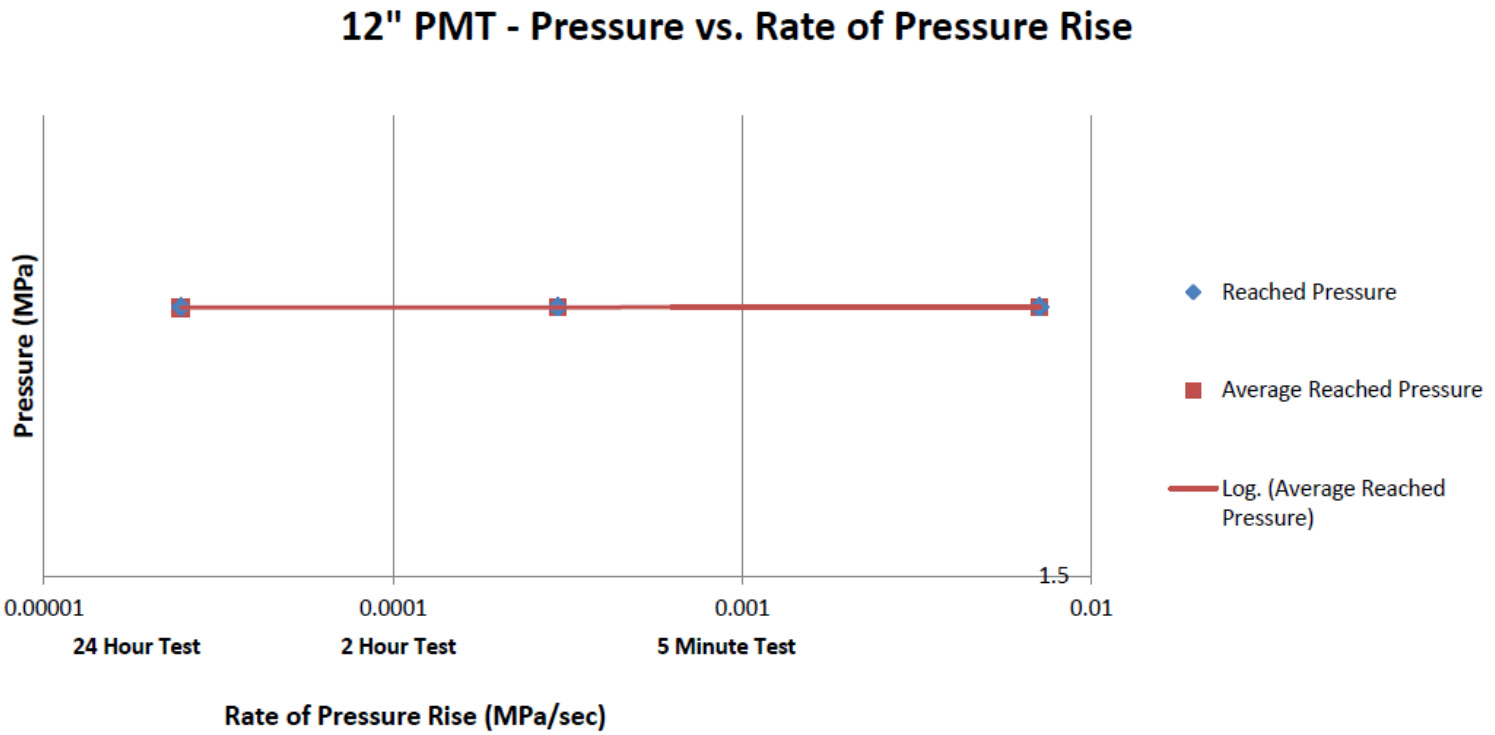
10" PMTs	Rate of Pressure Rise (MPa/sec)	Breaking Pressure (MPa)	Average Breaking Pressure (MPa)	Reached Pressure (MPa) [no Implosion]	Overall Average Pressure Reached (MPa)
5 Minute Test	0.0071016	1.95811107	1.75471573	2.06153243	1.76390874
	0.0071016	1.834005439		1.503057089	
	0.0071016	1.165213982			
	0.0071016	2.06153243			
2 Hour Test	0.00029647	2.06153243	1.372056701	2.06153243	1.470553233
	0.00029647	0.854949904			
	0.00029647	2.027058643			
	0.00029647	1.482372817			
	0.00029647	0.910107962			
	0.00029647	0.896318448			
24 Hour Test	0.00002468	0.896318448	1.082476895	2.068427187	1.411126992
	0.00002468	1.234161555		2.068427187	
	0.00002468	1.296214371			
	0.00002468	0.903213205			

11” PMTs



11" PMTs	Rate of Pressure Rise (MPa/sec)	Breaking Pressure (MPa)	Average Breaking Pressure (MPa)	Reached Pressure (MPa) [no Implosion]	Overall Average Pressure Reached (MPa)
5 Minute Test	0.0071016 0.0071016 0.0071016	2.054637672 2.089111459	2.071874566	2.06153243 2.068427187 2.068427187	2.068427187
2 Hour Test	0.00029647	0.882528933	0.882528933	2.06153243 2.068427187 2.068427187	1.770228934
24 Hour Test	0.00002468 0.00002468	1.165213982 0.88942369	1.027318836	2.013269129 2.068427187	1.534083497

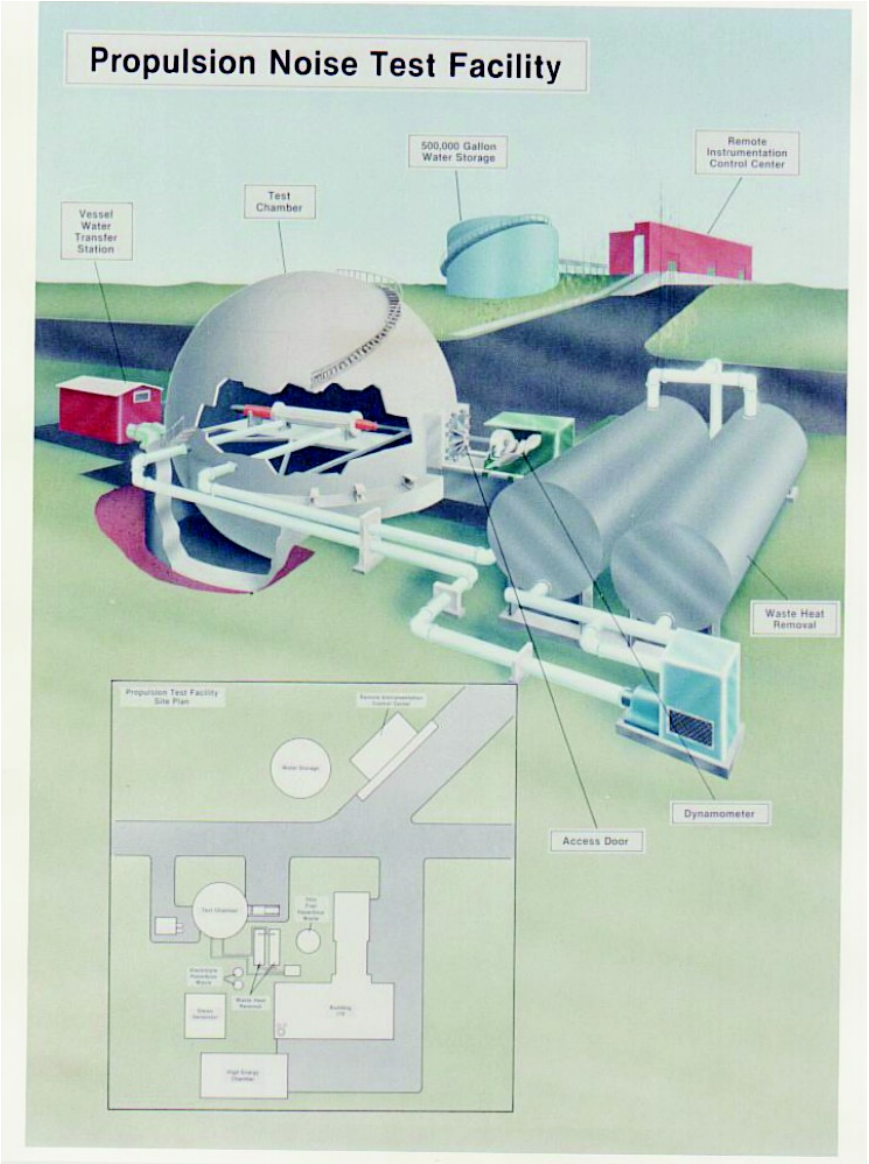
12” PMTs



20 PMTs for 5 mins and 2 hours tests
5 PMTs for 24 hours tests.

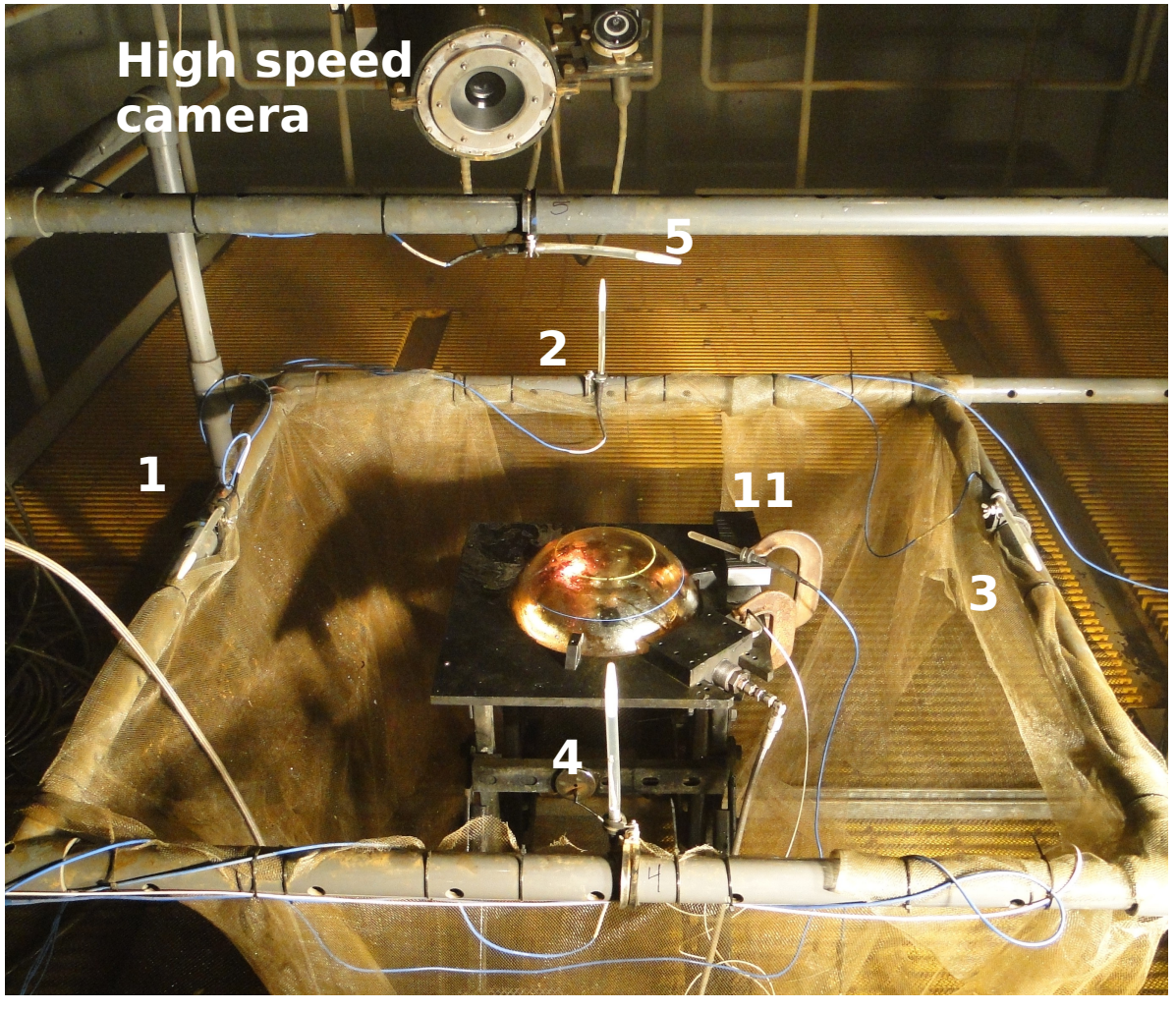
All survived.

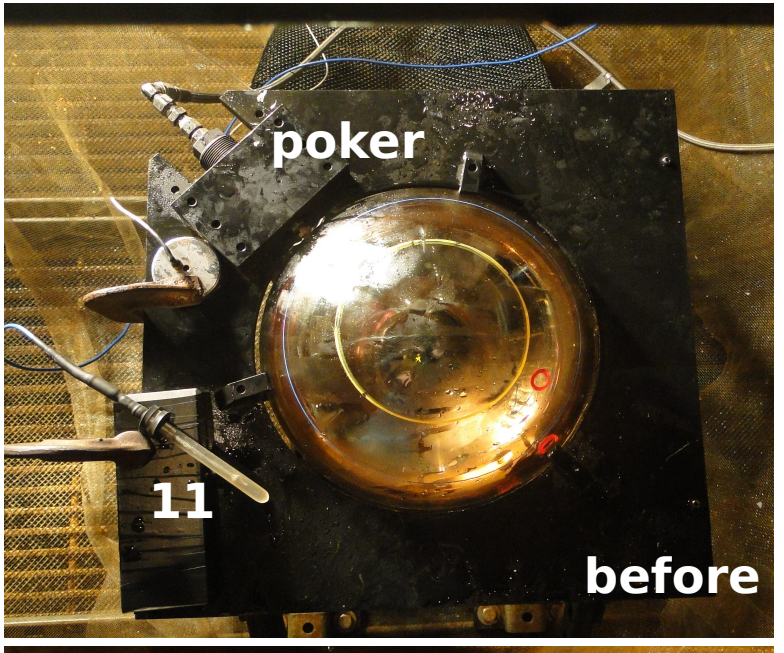
Navy Undersea Warfare Center (NUWC) Facility



- Cooperation between BNL and NUWC through Cooperative Research And Development Agreement (CRADA)
- 15m diameter
- 500,000 gallons of water
- Rated for 100 psi at the center

Single PMT Experimental Setup

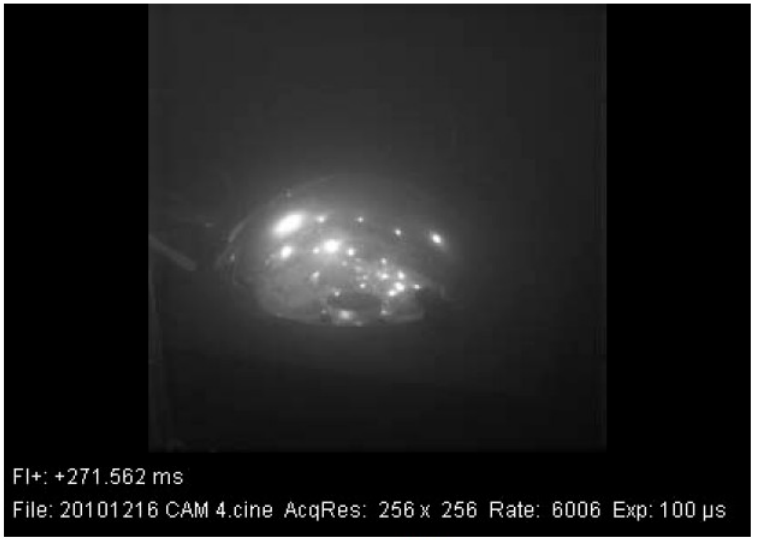




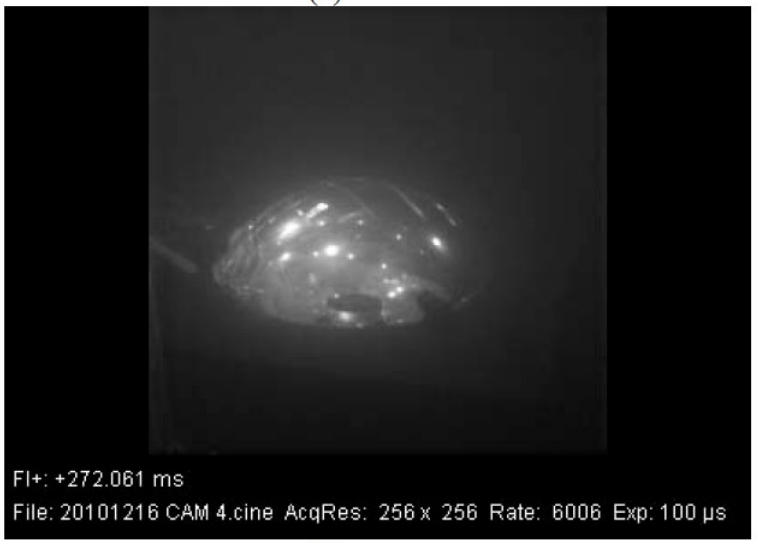
7 Water proof pressure sensors (PCB ICP)
2 High speed cameras

12/16/2010 Implosion Test

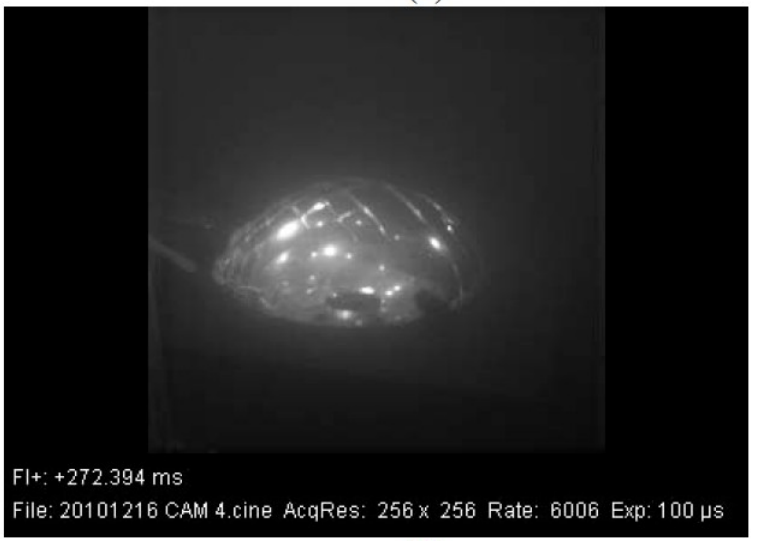
(a)



(b)

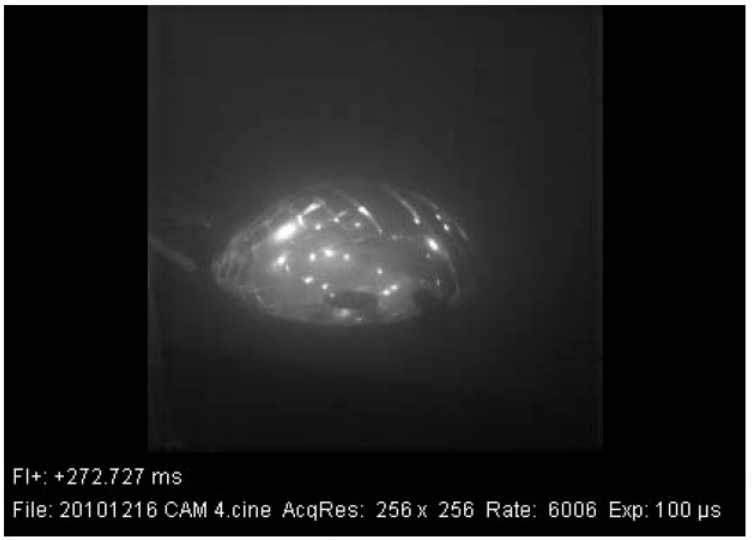


(c)

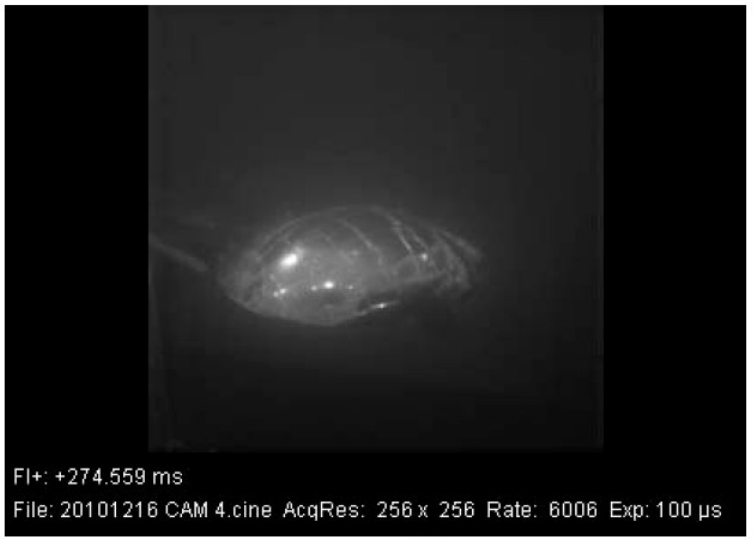


(d)

12/16/2010 Implosion Test



(e)



(f)

(g)

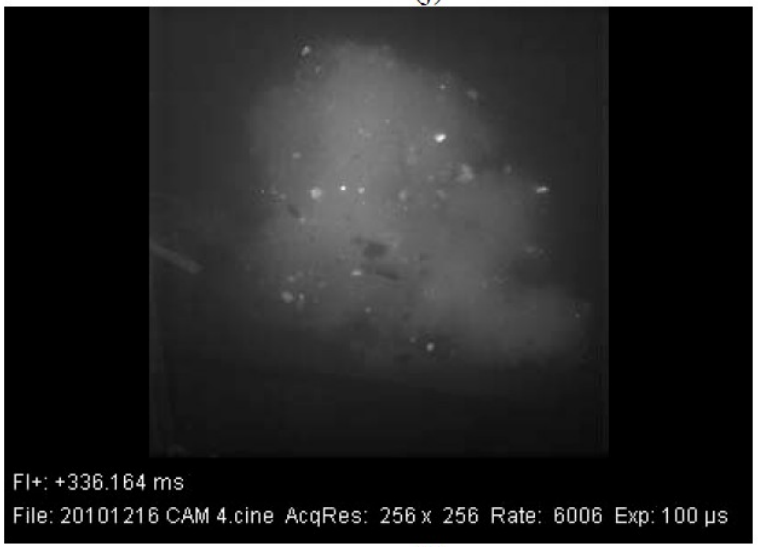
(h)

12/16/2010 Implosion Test

(i)

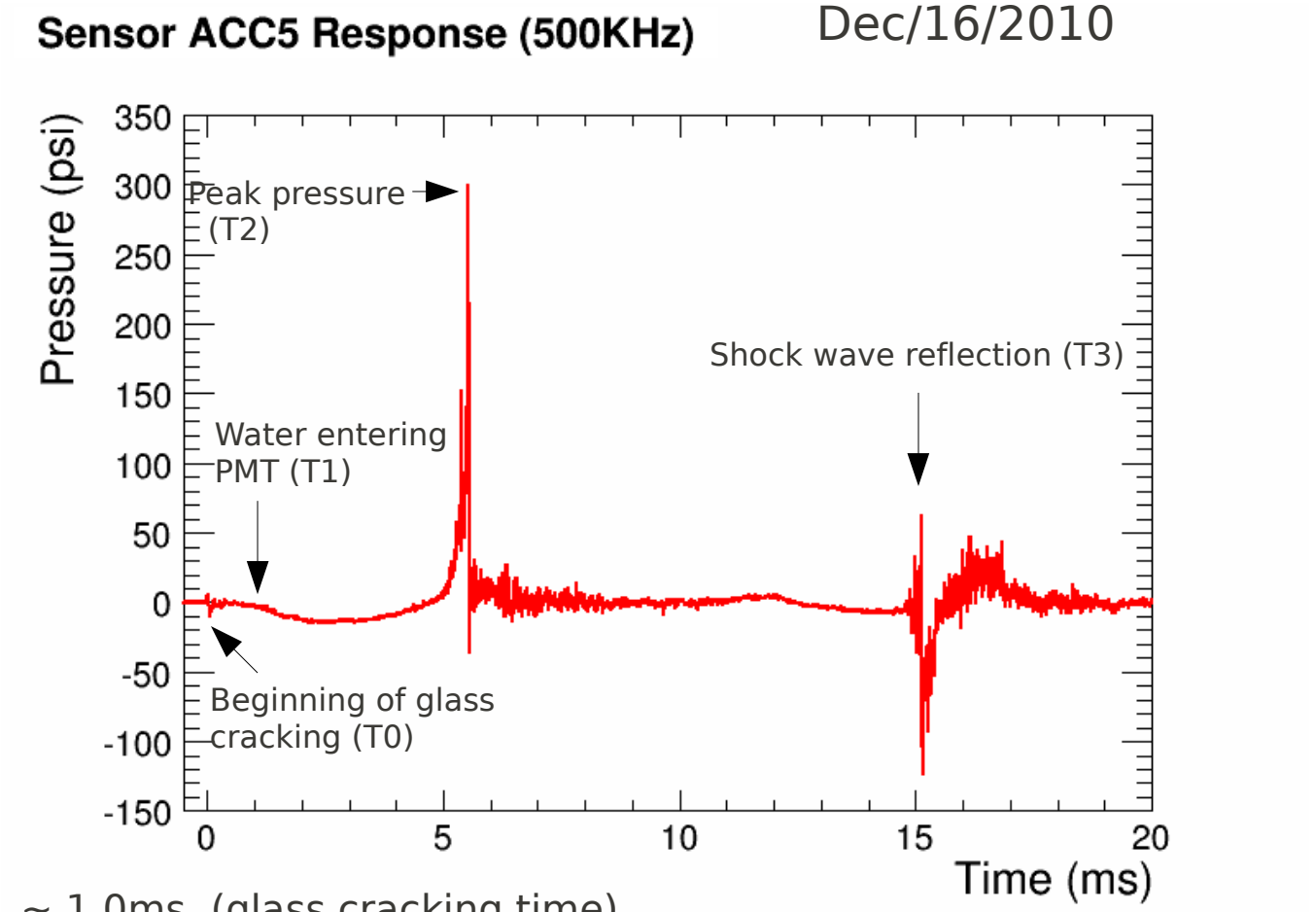
(j)

(k)



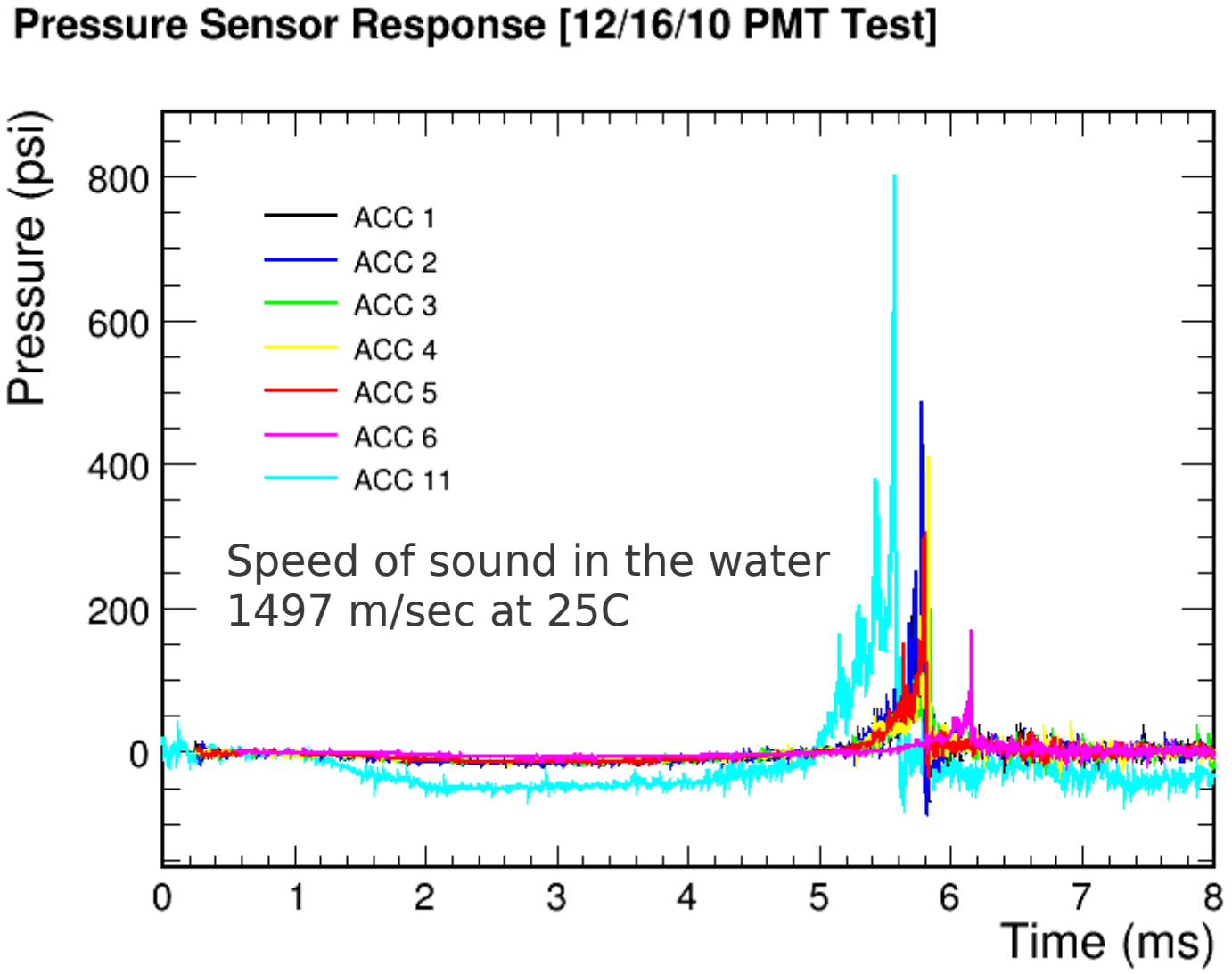
(l)

Blast Sensor Pulse Structure



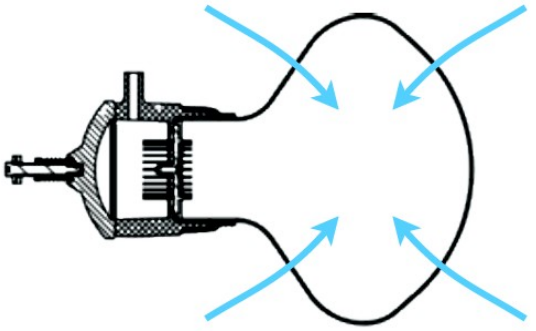
T1 – T0 ~ 1.0ms (glass cracking time)
T2 – T1 ~ 4.5ms >> 0.8ms (sound traveling time)
T3 – T2 ~ 10 ms (close to the speed of sound)

Multiple Sensors

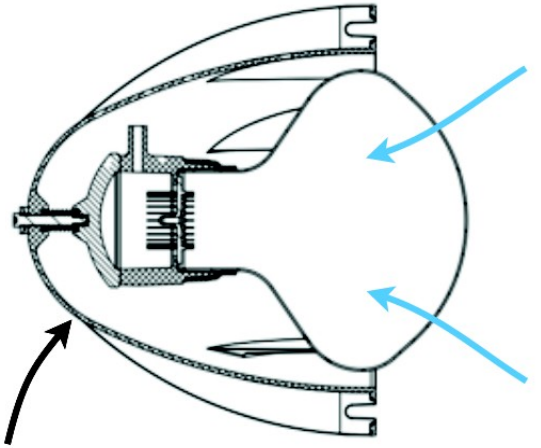


PMT with bucket

- A new design of PMT with "bucket" housing
- Expect: asymmetric flow spreads the energy out in time
  - Lower intensity of outgoing shock wave.

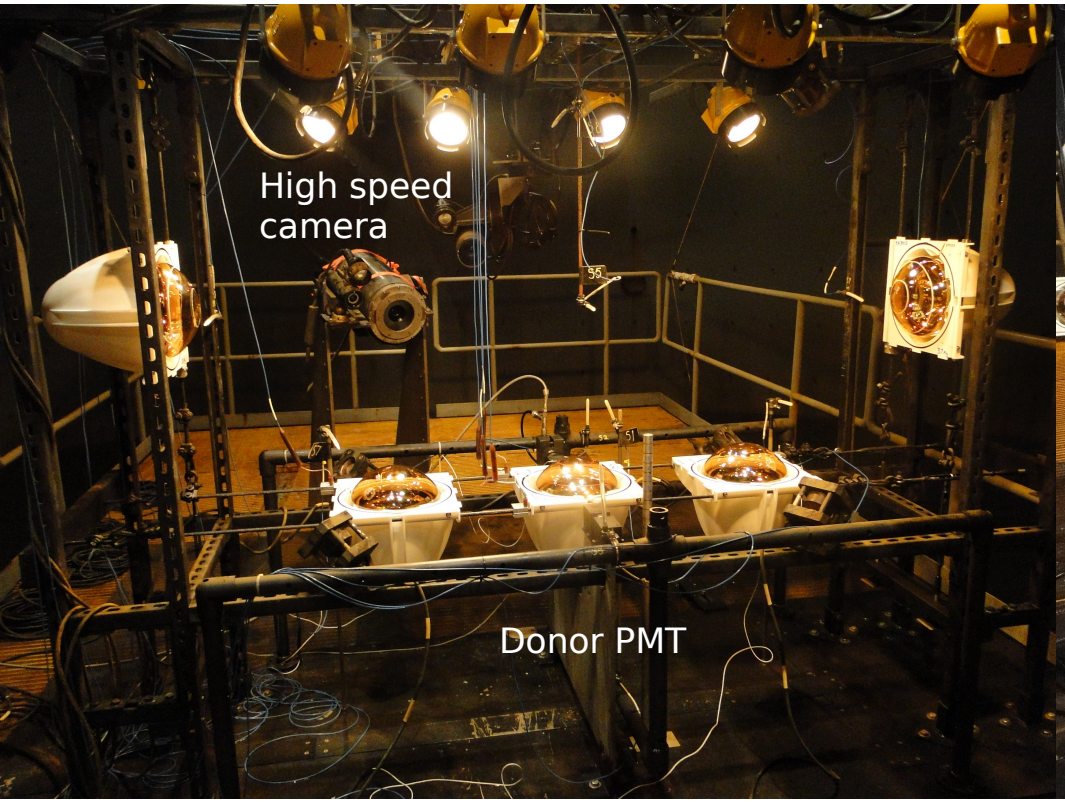


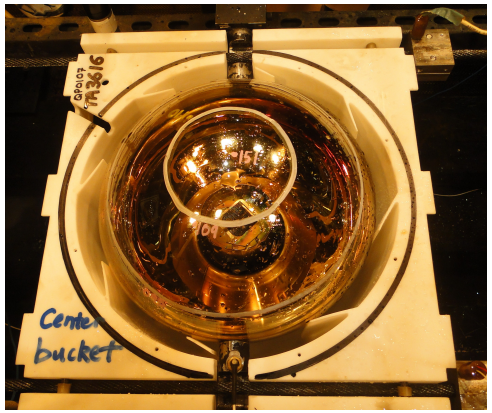
(Comparing to bare PMT)

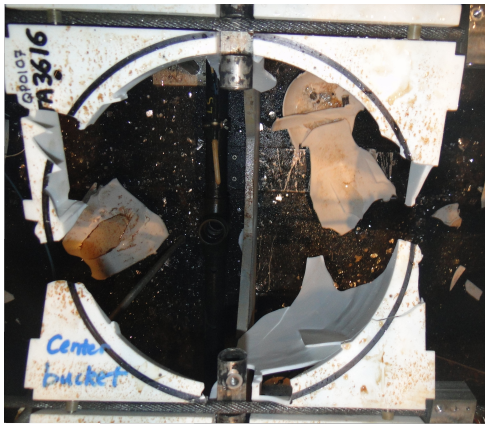


Bucket shape & ribs designed to withstand temporary differential pressure (DocDB-3574)

Multiple PMTs Experimental Setup

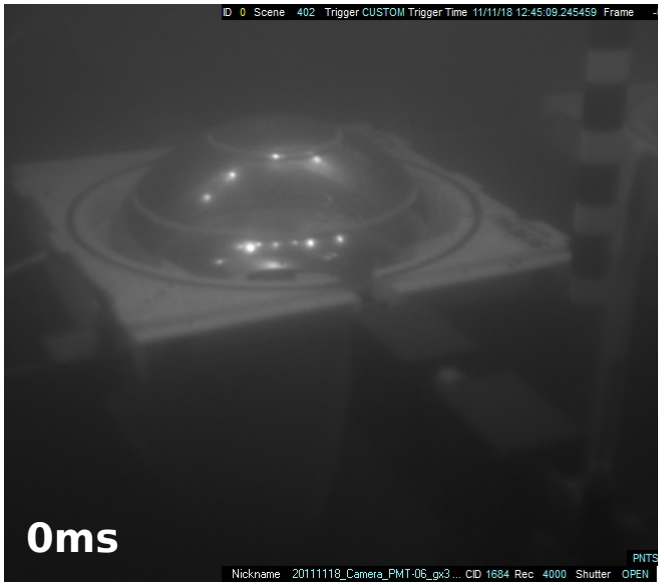


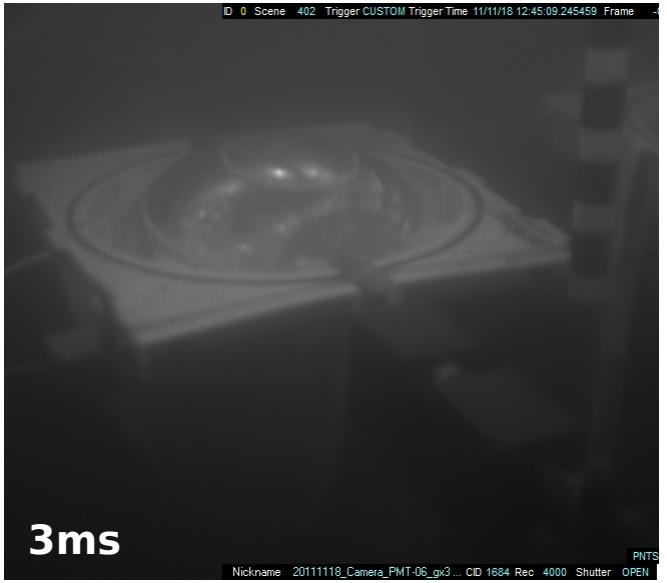




- 5 10” Hamamatsu R7081 tubes with prototyping housing are mounted on the cables
- Tubes are separated by 50cm from center to center
- 2 High speed cameras (4000f/s and 2000f/s)
- 10 Water proof pressure sensors (PCB ICP)
- 9 accelerometers are installed on the cables

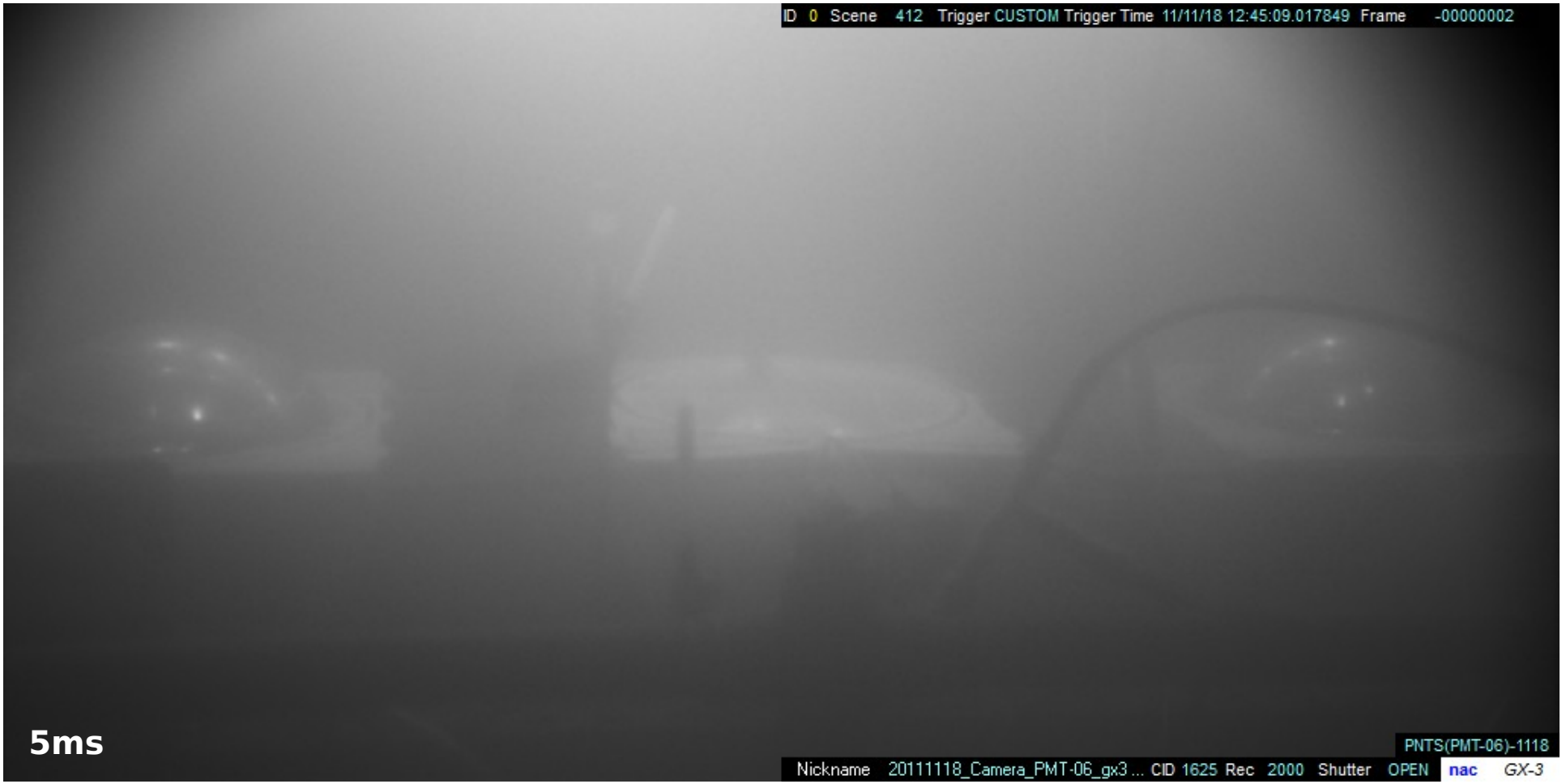
Camera 1 Screen Shots





Camera 2 Screen Shots

Camera 2 Screen Shots

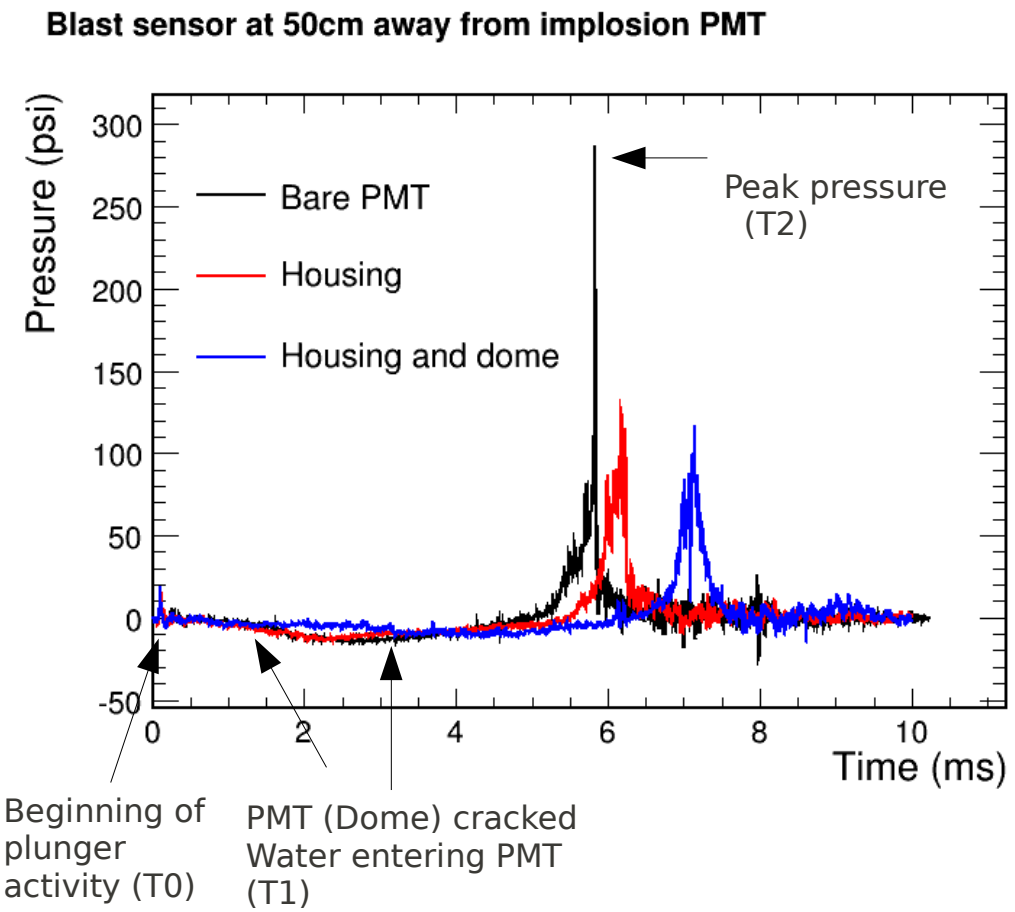


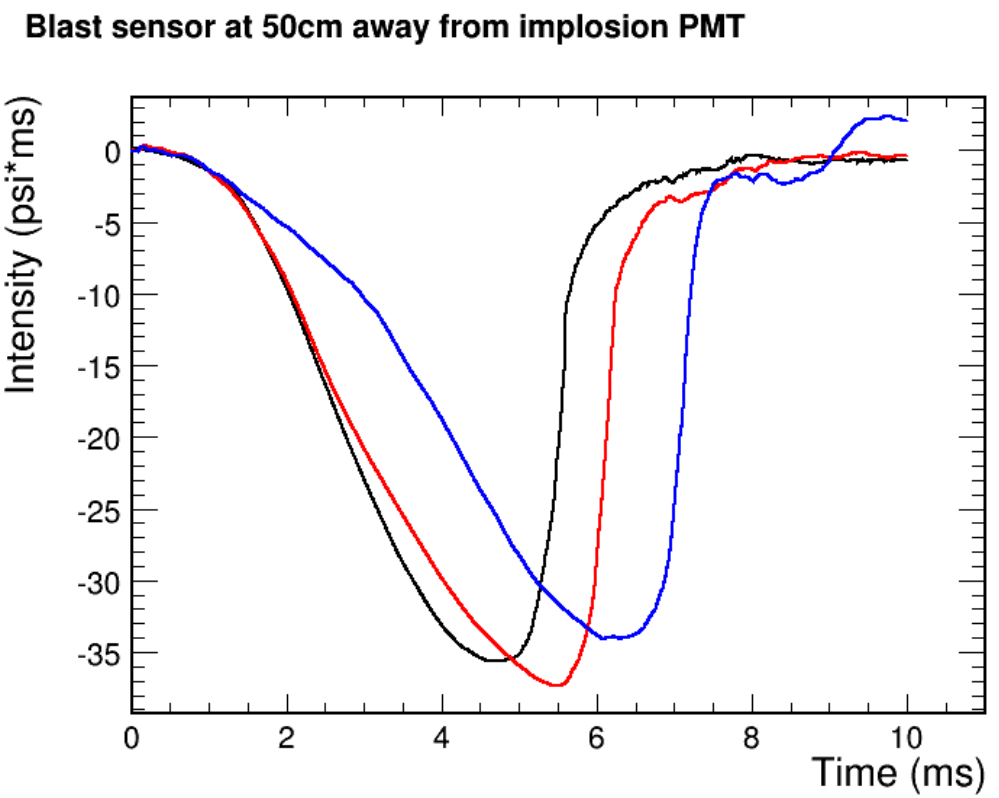
Camera 2 Screen Shots

Camera 2 Screen Shots

Camera 2 Screen Shots

Blast Sensor Response





- The typical time scale of the pmt implosion shock wave formation is around 6ms. The dome can slow the implosion process to 7ms.
- The shock wave peak amplitudes are greatly reduced by the housing.
- The total intensity (energy) of the shock wave is consistent in all cases. Dome can slightly reduce the shock wave energy.

Housing and Dome Effect

12/16/2010 Single PMT implosion W/O bucket 10” S/N RA0249

Sensors	distance(mm)	T0 (ms)	T2(ms)	T2-T0 (ms)	Peak (psi)	Intensity (psi*ms)
ACC11	152	0.000	5.570	5.570	801.6	150.0
ACC5	482	0.260	5.800	5.540	300.2	37.8
ACC1	521	0.260	5.785	5.525	426.9	38.0
ACC2	521	0.245	5.780	5.540	488.3	43.2
ACC3	521	0.235	5.830	5.595	287.2	35.8
ACC4	521	0.245	5.825	5.580	410.0	36.3
ACC6	991	0.560	6.150	5.590	169.2	20.3

11/16/2011 PMT implosion housing only 10” S/N TA3068

Sensors	distance(mm)	T0 (ms)	T2(ms)	T2-T0 (ms)	Peak (psi)	Intensity (psi*ms)
S1	279	837.143	843.161	6.018	437.22	67.21
S2	546	837.313	843.332	6.019	200.23	37.51
S3	508	837.151	843.331	6.180	123.61	37.69
S4	508	837.215	843.269	6.054	136.43	39.30
S5	508	837.298	843.333	6.035	199.24	31.95
S7	711	837.350	843.371	6.021	100.18	31.22
S8	1016	837.653	843.647	5.994	107.80	18.59
s10	1143	837.709	843.662	5.953	81.37	22.36

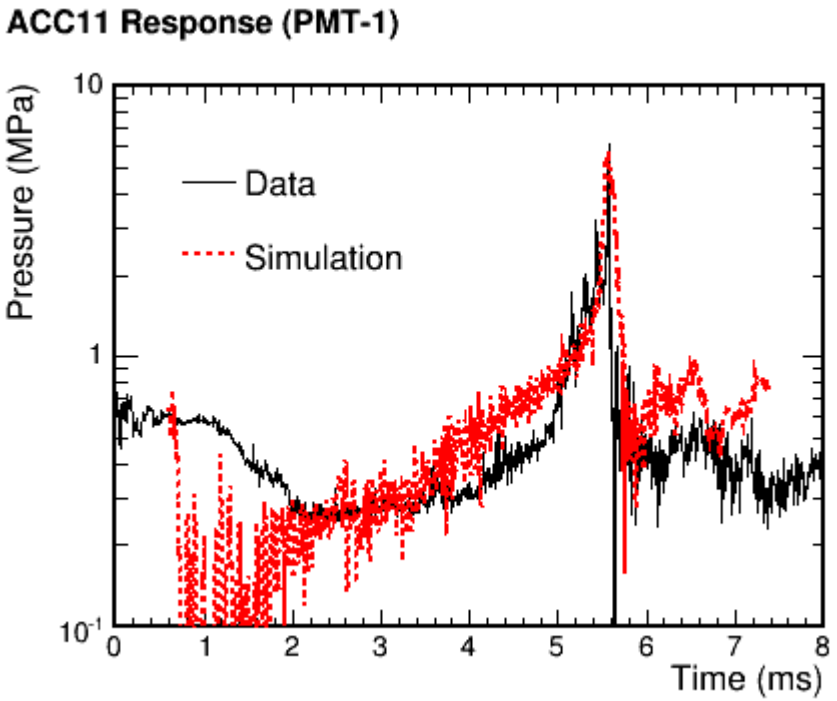
11/04/2011 Single PMT implosion with housing & dome 10” S/N ZT0007

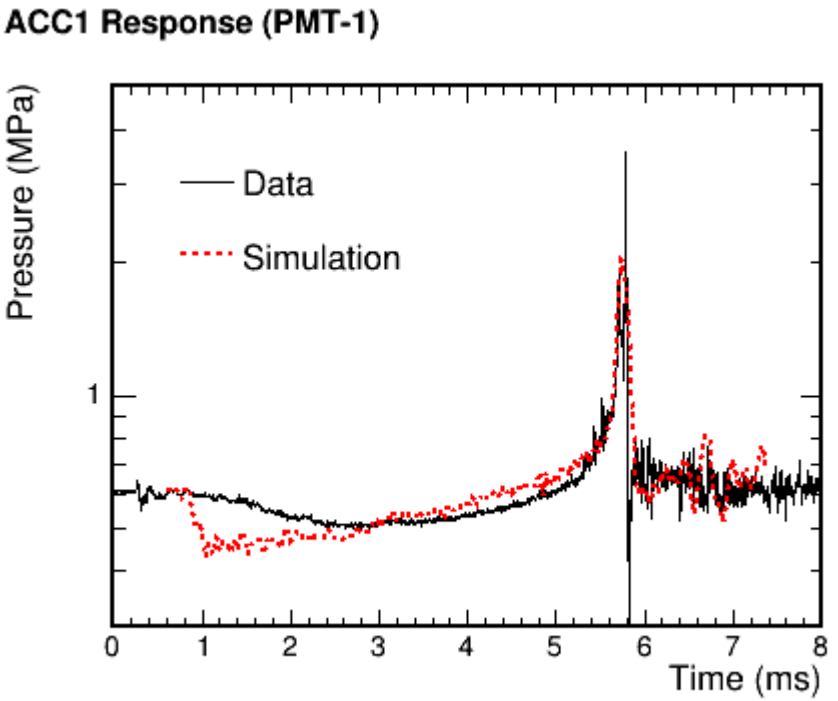
Sensors	distance(mm)	T0 (ms)	T2(ms)	T2-T0 (ms)	Peak (psi)	Intensity (psi*ms)
S1	279	299.994	306.854	6.860	366.95	64.37
S2	546	300.150	307.004	6.854	164.09	35.73
S3	508	300.004	307.144	7.140	116.98	36.45
S4	508	300.075	307.150	7.075	134.58	36.26
S5	508	300.136	307.317	7.181	252.12	45.33
S7	711	300.247	307.053	6.806	104.38	26.36
S8	1016	300.493	307.507	7.014	101.44	17.15
s10	1143	300.543	307.346	6.803	55.82	16.05

Simulation

LS-DYNA (general purpose transient dynamic finite element program)
Arbitrary Eulerian-Lagrangian (ALE) formulation that allows PMT glass and fluid to interface.

Based on a 2M+ fluid/solid element model and “adjusted” PMT glass constitutive and fracture relations, the implosion at 88 psi water pressure are simulated (~240 hrs)





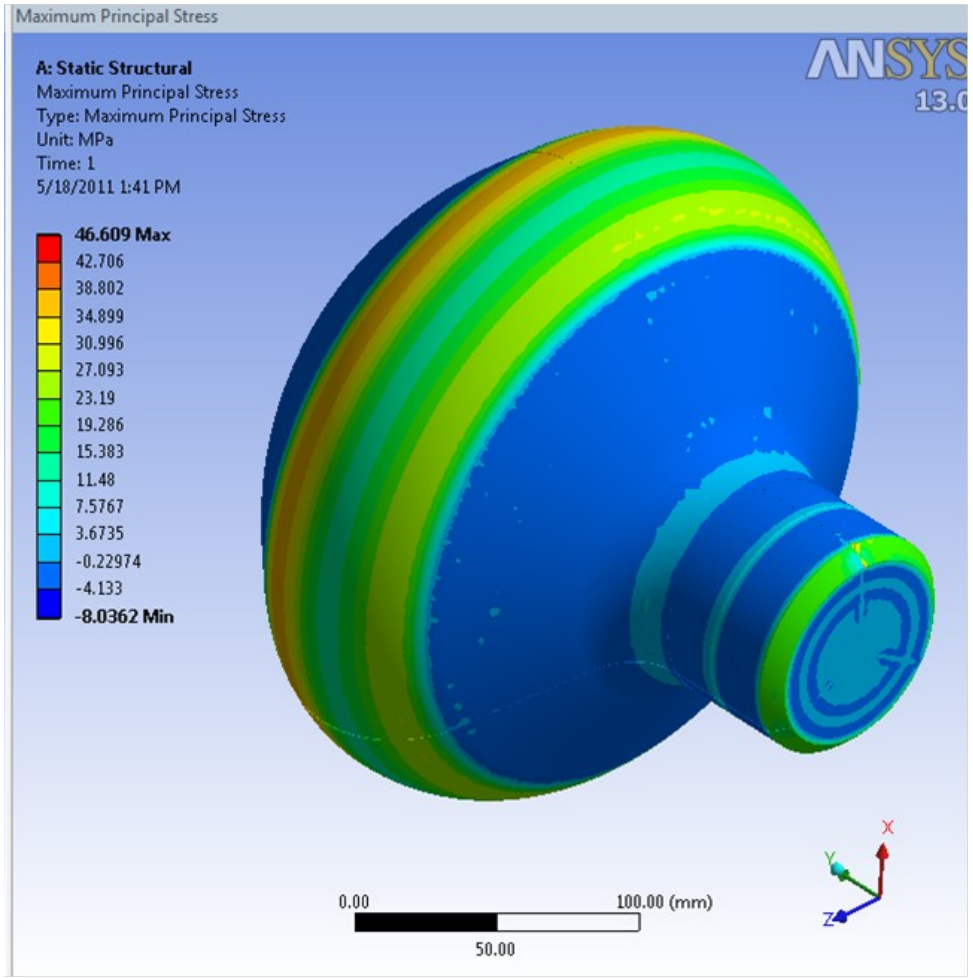
Conclusions

- Successfully set up slow rise pressure system at BNL.
- Multiple PMT hydrostatic pressure slow rise tests have been conducted.
- Successfully establish the PMT pressure test setup at NUWC.
- 3 identical 10” Hamamatsu PMT implosion tests with LBNE housing protection design were conducted at NUWC under 88psi. No PMT cascade implosions were found.
- The current PMT prototyping housing can effectively reduce the shock wave amplitude. The protection acrylic dome has fairly small effect on reducing the shock wave.
- PMT dynamic implosion are reasonably well simulated.

backup

Hydrostatic Stress Analysis

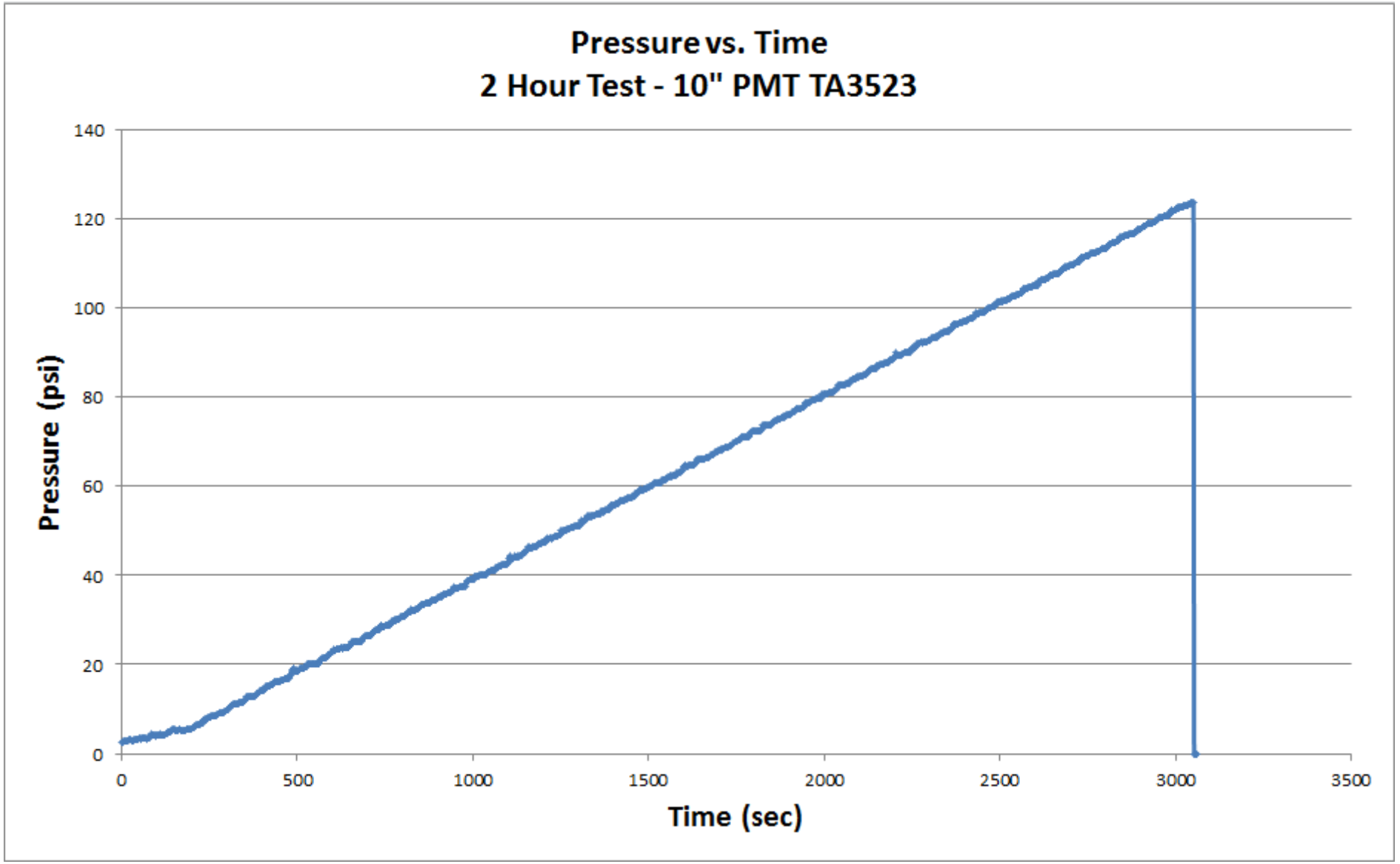
R. Sharma

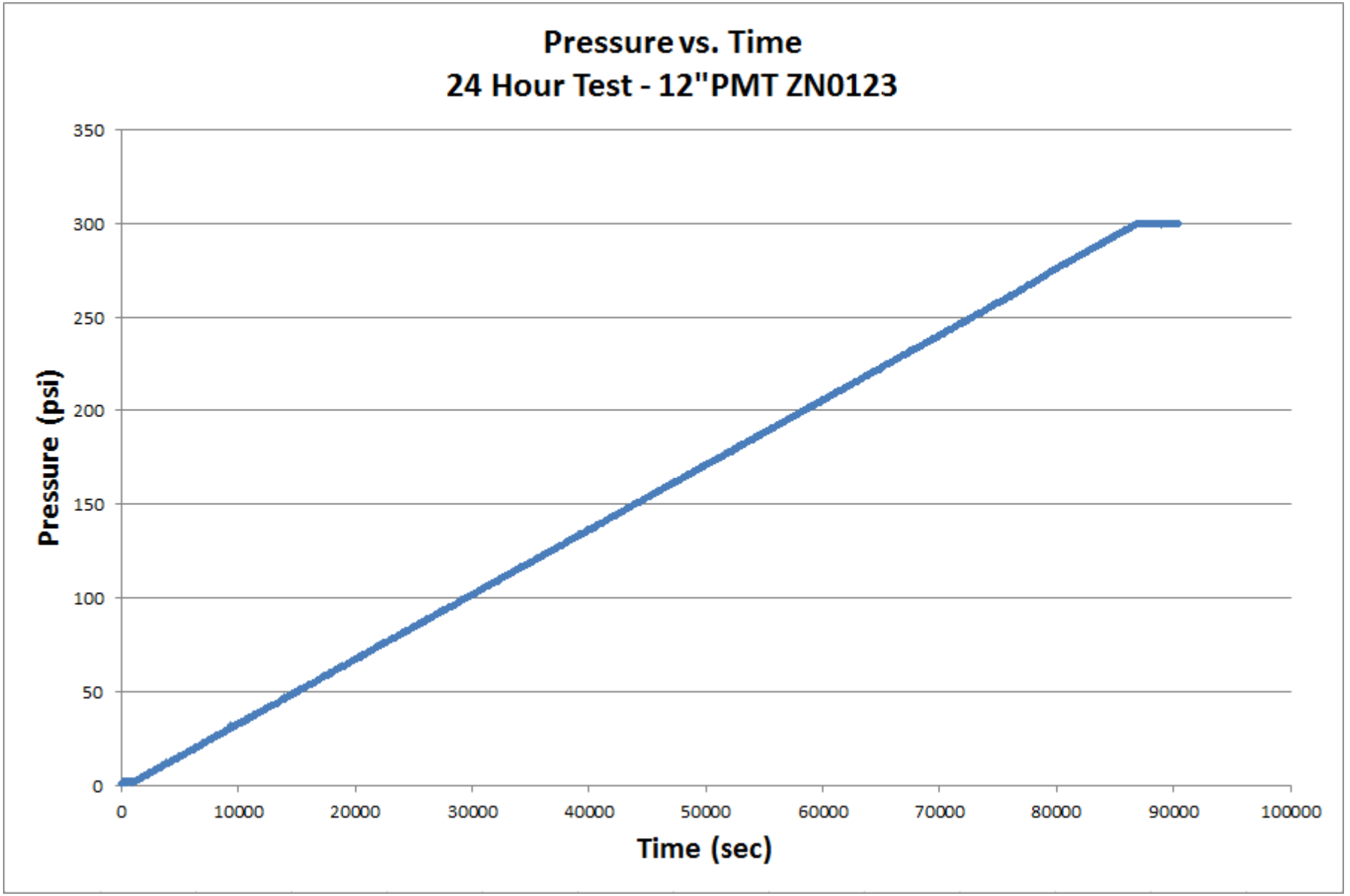


Hamamatsu R7081 under 1MPa (10 bar)

dydrostatic Stress Table (Hamatsu R7081)

Stress	Compressive (MPa)	Tensile (MPa)
maximal principal stress	46.6	-8.0
Maximal shear stress	47.5	0.0
Normal stress along X	37.7	-82.3
Normal stress along Y	34.6	-68.6
Normal stress along Z	37.9	-82.4
Shear stress in XY plane	42.7	-44.0
Shear stress in YZ plane	42.8	-42.6
Shear stress in XZ plane	36.9	-37.1


Pressure vs. Time
2 Hour Test - 10" PMT TA3523
Pressure (psi)
140
120
100
80
60
40
20
0
0
500
1000
1500
2000
2500
3000
3500
Time (sec)


Pressure vs. Time
24 Hour Test - 12"PMT ZN0123
Pressure (psi)
350
300
250
200
150
100
50
0
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Time (sec)

Simulation

LS-DYNA (general purpose transient dynamic finite element program)
Arbitrary Eulerian-Lagrangian (ALE) formulation that allows PMT glass and fluid to interface.
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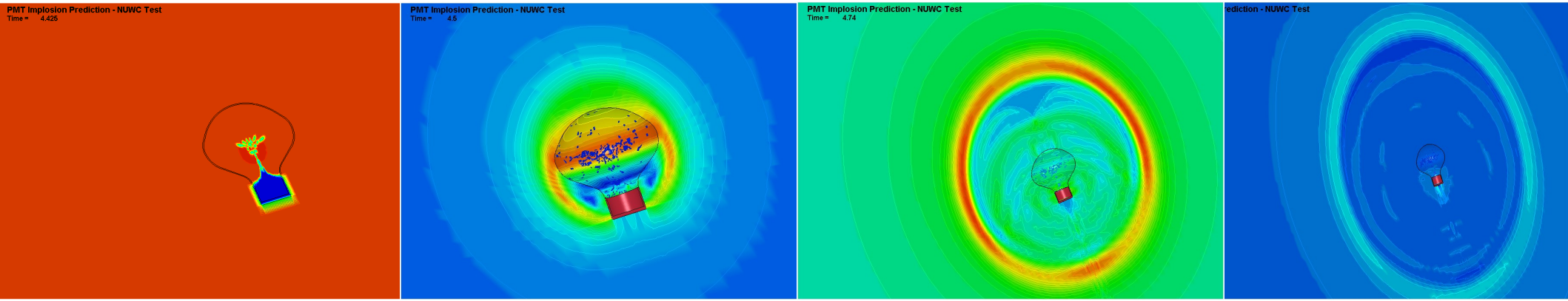

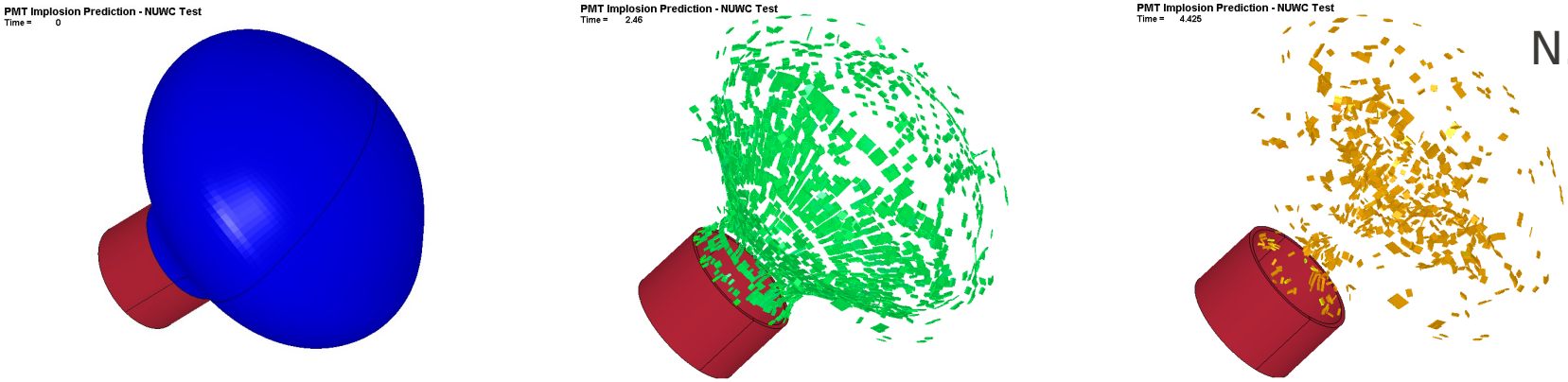

N. Simos

Electronics Shed

NUWC Control Room